Publications Committee

University of Texas Bulletin

No. 1759: October 20, 1917

THE FRICTION OF WATER IN PIPES AND FITTINGS

BY

F. E. GIESECKE

BUREAU OF ECONOMIC GEOLOGY AND TECHNOLOGY
J. A. Udden, Director
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Published by the University six times a month and entered as
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AUSTIN, TEXAS

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B257-618-1500

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The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.

Sam Houston

Cultivated mind is the guardian genius of democracy. . . . It is the only dictator that freemen acknowledge and the only security that freemen desire.

Mirabeau B. Lamar

THE FRICTION OF WATER IN PIPES AND FITTINGS.

OBJECT OF INVESTIGATION

The general object of the investigation described in this bulletin was the determination of the friction of water in pipes and fittings, with particular reference to the application of this information to the design of the piping of hot water heating systems.

GENERAL RESULTS

Briefly stated, the results attained so far are the following:

A. The friction of water, at a temperature of about 70 degrees F., in one foot of new and clean, black, standard pipe, ranging in size from ½ inch to 3 inches, is

$$.00685 \frac{v^{1.79d^{-.04}}}{d^{1.275}}$$ feet of water of the same density as that which flows through the pipe.

or, on an average, for the conditions named,

$$.00685 \frac{v^{1.77}}{d^{1.275}}$$ feet,

if v represents the velocity of the water in feet per second and d the internal diameter of the pipe in inches. (See pp. 7-12.)

B. The friction of water in galvanized iron pipe is slightly greater than that in black pipe. (See pp. 12-13.)

C. The friction of water in used pipe is greater than in new pipe; in the case of a 1½ inch galvanized iron pipe, which had been in use for seven years in a hot water heating system, it was found to be

$.003935\ v^{1.927}$ feet of water per foot of pipe as compared with $.003373\ v^{1.8115}$ for a new galvanized iron pipe of the same side. (See pp. 13-14.)

D. The friction of water in standard wrought iron couplings is very small; for a ¾ inch pipe and a velocity of one foot per second it is equal to that in a ¾ inch pipe whose length is equal to three diameters, and for a 1 inch pipe it is equal to that in a 1 inch pipe whose length is equal to one diameter. (See pp. 14-16.)

E. The friction of water due to the burrs which are left in pipes by the ordinary pipe cutter when the ends of the pipe are not reamed is considerable, particularly in the smaller sizes. For a ¾ inch pipe and a velocity of one foot per second the friction due to a pair of burrs is equal to that in a ¾ inch pipe whose length is equal to nineteen diameters, and for a 1 inch pipe it is equal to that in a 1 inch pipe whose length is equal to nine diameters. (See pp. 16-18 and Eqs. 35 and 39.)

F. The friction of water in a standard short radius, 90 degree elbow, after deducting for the length of the elbow, so that only the friction due to the change of direction of flow and that due to change of cross sectional area of conduit is considered, is, for elbows ranging in size from ½ inch to 2½ inches,

$$.0141 \frac{v^{1.96}}{d^{0.26}} \text{ feet of water.} \qquad \text{(See pp. 18-23.)}$$

For the range of sizes and velocities investigated, the friction of a standard 90 degree elbow is about the same as that of a pipe whose diameter is equal to that of the elbow and whose length is equal to twenty-five diameters. (See p. 22, diagram.)

G. The friction of water in short radius, ordinary elbows is greater than that in long radius, ordinary elbows; the difference is variable, decreasing with the velocity; for a 1¼ inch elbow and a velocity of one-half foot per second the friction in a short radius elbow is about five times as great as in a long radius elbow; for a velocity of two feet it is about twice as great. (Compare Lines 54 and 56 of Fig. 11).

The friction of water in short radius, drainage elbows is greater than that in long radius, drainage elbows; the difference is not as variable as in ordinary elbows; for a 1¼-inch elbow and a velocity ranging from one-half foot to two feet per second, the friction in a short radius, drainage elbow is about twice as great as in a long radius, drainage elbow. (Compare Line 58 with Lines 60 and 62 in Fig. 11).

The friction of water in drainage elbows (of the types and size tested in these experiments) is about twice as great as that in ordinary elbows. (Compare Line 54 with Line 58, and Lines 60 and 62 with Line 56 in Fig. 11).

H. The friction of water decreases as its temperature increases. For temperatures ranging from 60 degrees F. to 140 degrees F. (and, probably, somewhat beyond these limits) the friction in one foot of clean black pipe is

$$\frac{.01533}{t^{.19}} \frac{v^{1.77}}{d^{1.275}}$$ feet of water of the same temperature as that flowing through the pipe, t being expressed in Fahrenheit degrees (See pp. 25-28.)

GENERAL METHOD OF TESTING.

The apparatus used in these experiments is shown in Fig. 1. It consists essentially of two tanks, *B* and *C*, connected by a pipe line containing the pipes and fittings to be tested, and devices for measuring the velocity of the water in the pipes tested and the corresponding friction heads.

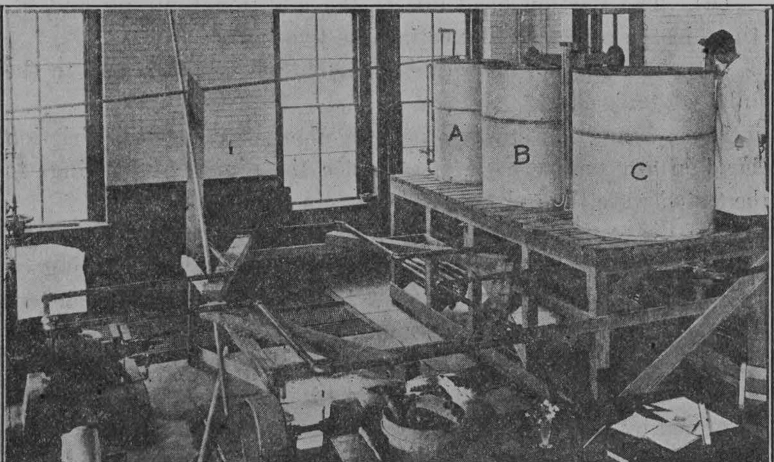


Fig. 1

In conducting the experiment, water was first admitted to the tank *A* in which it was kept at a practically constant level by means of float valves and an overflow pipe.

From the tank *A* the water passed to the tank *B* through a large pipe connecting the bottoms of the two tanks so that the two tanks really acted as one, the tank *A* acting as a baffle-plate for the tank *B*.

From the tank *B* the water passed to the tank *C* through the pipes and fittings to be tested and through such additional piping and fittings as were necessary to connect the tanks; the additional piping and fittings remained unchanged during any one series of tests.

From the tank *C* the water was discharged through a series of valves into a weighing tank.

The difference in elevation of the water in the tanks *B* and *C* is the head of water, of that particular density, necessary to produce the flow which is in progress at that particular time from the tank *B* to the tank *C*; it includes:

(a) The friction head due to the pipe and fittings being tested;

(b) The friction head due to the additional piping and fittings in the pipe line connecting the two tanks;

(c) The friction head due to the outlet of tank *B* and to the inlet of tank *C*.

Items *b* and *c* were grouped together as a constant friction head in any one series of tests since the piping and fittings to be tested were the only variable factors in any one series.

The difference in elevation of the water in tanks *B* and *C* was read directly by means of hook gauges; the zero reading of each gauge was determined at the beginning or end of each test by permitting the water to come to rest and to the same level in both tanks.

The velocity of the water in the piping to be tested was determined by weighing the water which passed through the piping in a definite period of time, generally five minutes.

The diameters of the pipes were determined by weighing the water necessary to fill the pipe after the same had been thoroughly cleaned, taking account of the temperature of the water used for that purpose.

The velocity of flow from the tank *B* to the tank *C* was regulated by adjusting the discharge valves of the tank *C*.

In conducting any one test it was necessary to let the water flow through the apparatus until a uniform rate of flow was attained. When this condition existed the elevations of the water in the three tanks were constant, and two successive readings would show the same difference in elevation of the water in the tanks *B* and *C*, and the same weight of water discharged from the tank *C* in a given time.

In conducting the tests readings were taken at intervals until two successive readings were obtained which were exactly alike, both with regard to the velocity of the water in the pipe being tested, and the corresponding friction head.

When these readings had been obtained the valves controlling the discharge from the tank *C* were changed so as to secure a different velocity and correspondingly different friction head.

In this way a number of readings were obtained for each particular pipe or fitting tested; during these tests the friction head varied from 1/50 inch to two feet, and the velocity from ½ inch to three feet per second.

Results and Method in Detail

A. The friction of water in new and clean, black, standard pipe.

The pipe line connecting tanks *B* and *C* was arranged so as to include two joints of 1¼ inch pipe, having a total length of 41.07 feet.

The average diameter of this pipe was 1.361 inches.

The discharge valves of the tank *C* were adjusted so that the velocity of the water in the 1¼ inch pipe was very low; the water was then allowed to run until consecutive readings showed that the velocity and the difference in elevation of the water in tanks *B* and *C* were constant; this generally required from thirty to sixty minutes; for the larger pipes it required less and for the smaller pipes more time; for the three inch pipe a constant flow could be secured in about twenty minutes after the discharge valves had been set; for the half inch pipe it required about two hours.

When the valves happened to be set so that the resulting velocity was near the critical velocity it was impossible to secure a constant flow.

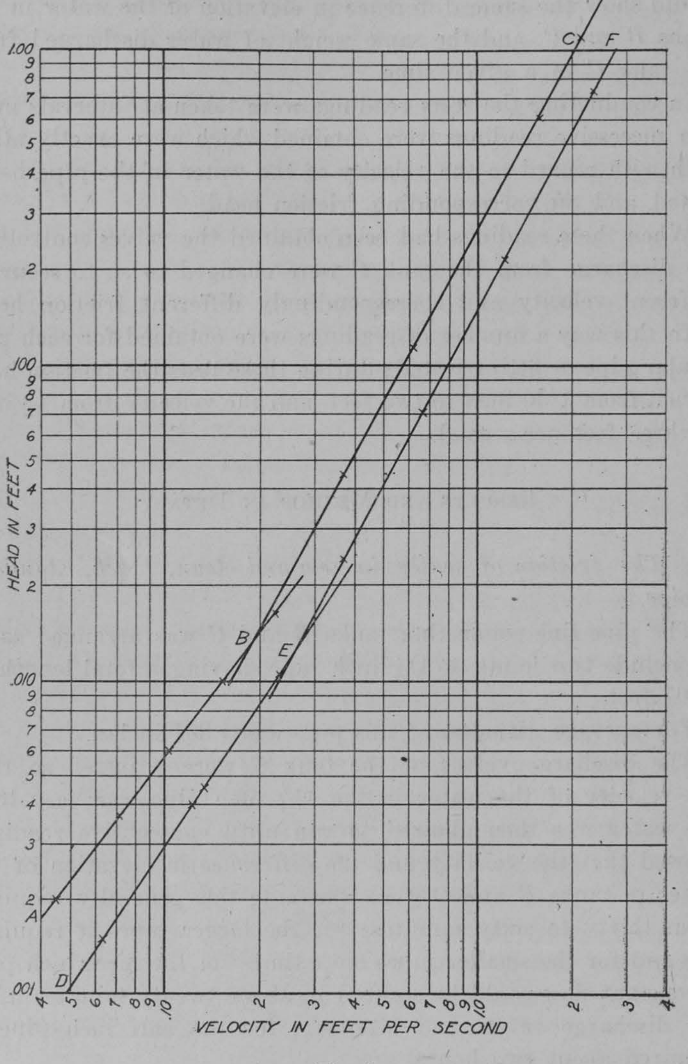


Fig. 2

After the final reading had been taken for the first adjustment of the discharge valves, these valves were opened slightly, and readings taken until the flow was again constant, the final readings were again recorded and the discharge valves opened a little more; this process was repeated until a sufficient number of readings had been secured; the data observed in these tests are shown in Table 7, page 32.

The observed velocities with their corresponding pressure heads were then plotted as shown in Fig. 2 by the line *A B C*. In this case, the critical velocity is shown by the point *B*; it is about 2/10 feet per second.

The equation of the line *B C* was determined by reading directly from the diagram and by calculating the velocities corresponding to several friction heads. This equation, No. 10, is recorded under Table 7.

The two joints of $1\frac{1}{4}$ inch pipe were then removed from the line connecting the tanks *B* and *C* and a piece eight feet long cut from each joint; these two pieces, having a combined length of sixteen feet, were then inserted in the line connecting the tanks *B* and *C*, after the pipe ends had been reamed.

The experiment described above was then repeated and the observed data recorded as shown in Table 8. The velocities and corresponding friction heads were plotted as shown by the line *D E F* of Fig. 2. The equation of the line *E F* was determined as described above and recorded as Eq. 11 under Table 8.

The pipe lines used to connect the tanks *B* and *C* in the two tests, the results of which are shown by Tables 7 and 8, were exactly alike except that in the first case there were 25.07 feet more of $1\frac{1}{4}$ inch pipe than in the second case. The difference in friction, shown by the vertical distance between the lines *BC* and *EF* of Fig. 2, or by Eqs. 10 and 11, was due to 25.07 feet of $1\frac{1}{4}$ inch pipe.

By means of Equations 10 and 11 the friction heads were calculated for three or four different velocities; the differences between these friction heads were divided by 25.07 and in that way the friction head due to one foot of $1\frac{1}{4}$ inch pipe determined and plotted as shown in Fig. 3 by line 12; the equation of this line was then determined and recorded as Equation 12, under Table 8.

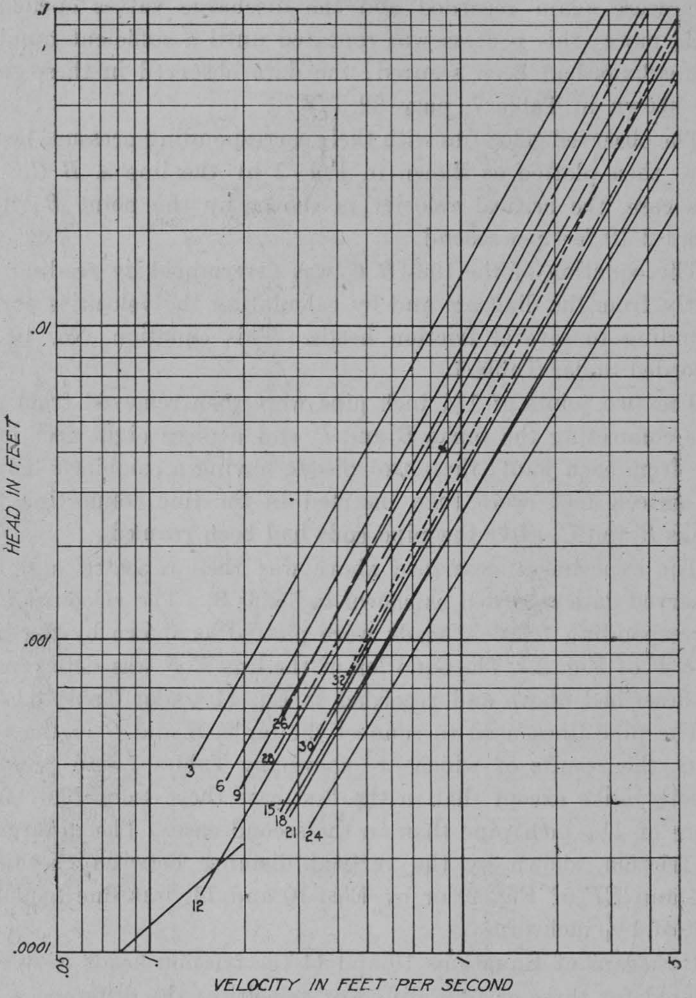

.1
.01
.001
.0001
HEAD IN FEET
.05
.1
1
5
VELOCITY IN FEET PER SECOND
3
6
9
12
15
18
21
24
26
28
30
32

Fig. 3

In this manner tests were made with ½, ¾, 1, 1¼, 1½, 2, 2½, and 3 inch standard black pipe; the observed values are recorded in Tables 1 to 16; the equations showing the friction heads for one foot of pipe of the several sizes named are numbered 3, 6, 9, 12, 15, 18, 21, and 24, respectively, and recorded under the respective tables of observed data; the equations were derived from the lines shown in Fig. 3 and bearing the same numbers as the respective equations.

Having found the equations which express the relation between the friction head and the velocity for each of the eight pipe sizes named above, a general equation for the several sizes was determined in the following manner:

Each of the eight equations is of the form $h = kv^n$.

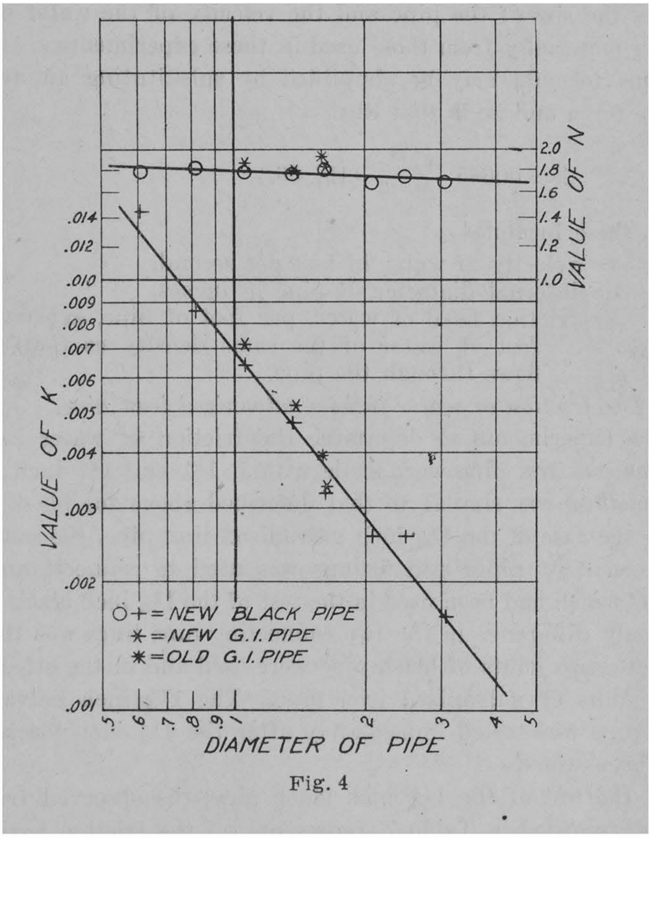


Fig. 4

The eight values of k and of n were plotted as functions of the diameter of the pipe, as shown in Fig. 4; two lines were then drawn so as to represent, as nearly as possible in each case, the average value of k and the average value of n.

The equation of the line representing the average value of k is: $k=.00685d^{-1.275}$; the equation of the line representing the average value of n is: $n=1.79d^{-.04}$; consequently the general equation for the friction head of water in one foot of clean black standard pipe is

$$h=.00685\frac{v^{1.79d^{-.04}}}{d^{1.275}}$$

when the temperature of the water is about 70 degrees F. and when the size of the pipe and the velocity of the water do not differ materially from those used in these experiments.

This formula may be simplified by substituting an average value for n and is, in that case,

$$h=.00685\frac{v^{1.77}}{d^{1.275}} \quad \text{(Eq. 66.)}$$

In these formulas

v=velocity of water in feet per second,
d=internal diameter of pipe in inches,
h=friction head of water, per foot of pipe, expressed in feet of water of the same density as that which flows through the pipe.

B. The friction of water in new galvanized iron pipe.

The experiments to determine the friction of water in new galvanized iron pipe were made with 1, 1¼ and 1½ inch pipe; the method was similar to that described above for black pipe.

In the case of the 1¼ inch galvanized iron pipe, the same arrangement of pipes and fittings was used to connect tanks *B* and *C* which had been used in the test of the 1¼ inch black pipe; the only difference in the two connecting pipe lines was that in one case two joints of black pipe were used and in the other case two joints of galvanized iron pipe. The 1¼ inch galvanized iron pipe was tested immediately after the 1¼ inch black pipe had been tested.

In the test of the 1¼ inch black pipe, the observed friction heads, recorded in Table 7, represent (a) the friction head due to the 41.07 feet of 1¼ inch pipe; (b) the friction head due to the additional piping and fittings in the line connecting the two tanks; (c) the friction head due to the outlet of the tank *B* and the inlet of the tank *C*.

Items *b* and *c* were exactly the same in the test of the galvanized iron pipe as in the test of the black pipe for the same velocities; they were grouped together as a "constant" friction head.

Having determined the friction head due to one foot of 1¼ inch black pipe (Eq. 12), the friction head due to 41.07 feet was calculated and deducted from the total pressure heads recorded in Table 7; the remainders were the "constant" friction heads referred to above as items *b* and *c*.

The 1¼ inch galvanized iron pipe was then tested in the same manner as the 1¼ inch black pipe; the observed data are shown in Table 18.

From the friction heads shown in this table the "constant" friction heads, as calculated from the 1¼ inch black pipe test, were deducted and the remainders divided by 41.245, the total length, in feet, of the two joints of galvanized iron pipe; the several quotients represented the respective friction heads in one foot of 1¼ inch galvanized iron pipe.

These values were plotted in Fig. 3 and Line 28 drawn through the same; from this line Eq. 28 was determined as recorded under Table 18.

In a similar way the 1 inch and 1½ inch galvanized iron pipes were tested and the results recorded in Tables 17 and 19. The corresponding lines, 26 and 30, in Fig. 3 were drawn, and Eqs. 26 and 30 determined and recorded under Tables 17 and 19.

The values of k and n of Eqs. 26, 28, and 30 are shown in Fig. 4 for comparison with those for new black pipe.

C. The friction of water in used pipe.

In designing a heating system it is necessary to take into account the condition of the pipes after the system has been in use for some time; it is therefore important to know how the friction head in a pipe is affected by the incrustation which occurs in pipes during their use as parts of hot water heating systems.

To get some idea of the changes in the friction factors with the use of the pipe, a 1½ inch galvanized iron pipe, 36.46 feet long, was taken out of the hot water heating system of the University green house where it had been in continuous use for about seven years.

This pipe was tested in the same manner as the 1½ inch new galvanized iron pipe; the observed data are recorded in Table 20; the friction head for one foot of this pipe is shown by Line 32 of Fig. 3, and by Eq. 32 under Table 20.

The incrustation on the interior surface of the pipe was sufficient to decrease the average internal diameter of the pipe about 1/100 inch.

A comparison of Eqs. 32 and 30 shows that the coefficient of v is about 17% greater in the case of the used pipe than in the case of the new pipe and that the exponent is about 6% greater.

For comparison with other pipes, the values of k and n of Eq. 32 are shown in Fig. 4.

D. The friction of water in standard black couplings.

A line of pipe is made up by attaching the several joints of pipe to each other by means of screwed couplings.

To calculate the friction head due to such a line it is necessary to know the friction head due to one foot of the pipe and also that due to one coupling, unless the friction head due to such a coupling is so small as to be negligible.

To determine the friction head due to such couplings experiments were made with ¾ inch and 1 inch couplings, in connection with the tests made on ¾ inch and 1 inch pipe according to the following method:

After the tests of the ¾ inch pipe had been completed as shown by Table 3, the two joints of ¾ inch pipe were cut, each into five parts of approximately equal lengths; the sixteen cut ends were well reamed and threaded and connected by means of eight couplings; the pipe line connecting the tanks B and C was then exactly like the one which gave the results shown in Table 3 except that eight couplings had been introduced into the line and the length of the line increased slightly by these eight couplings.

The test was then conducted as before and the results recorded in Table 22. The differences between the friction heads found

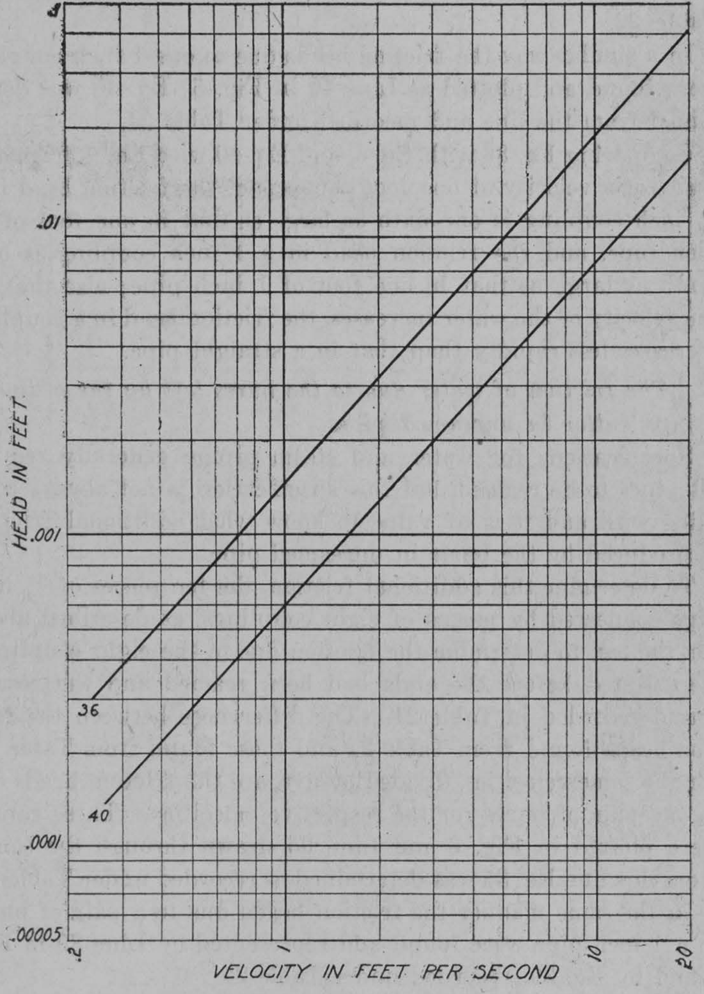

HEAD IN FEET
.01
.001
.0001
.00005
36
40
.2
1
10
20
VELOCITY IN FEET PER SECOND

Fig. 5

from Table 3 and those found from Table 22, for the same velocities, divided by eight are the friction heads due to one 3/4 inch coupling; these values were plotted in Fig. 5, Line 36; Eq. 36 was determined from the line and recorded under Table 22.

In a similar way the friction heads due to one 1 inch coupling were found and plotted as Line 40 in Fig. 5; Eq. 40 was determined from the line and recorded under Table 24.

Comparing Eq. 36 with Eq. 6, and Eq. 40 with Eq. 9 it appears that, for a velocity of one foot per second, the friction head in a 3/4 inch coupling is one-sixth as large as that in one foot of 3/4 inch pipe, and the friction head in a 1 inch coupling is one-tenth as large as that in one foot of 1 inch pipe; also that, as the velocity of the water increases, the friction head in a coupling increases less rapidly than that in a straight pipe.

E. The friction of water due to the burrs left by the ordinary pipe cutter in unreamed pipes.

Specifications for water and steam piping generally require all pipes to be reamed, but this specification is not always complied with and it is of value to know what additional friction is produced by the burrs in unreamed pipe.

To determine this additional friction, the ten pieces of 3/4 inch pipe connected by means of eight couplings, as described above for the test to determine the friction due to the eight couplings, were tested before the ends had been reamed and the results found recorded in Table 21. The differences between the friction heads found from Table 21 and those found from Table 22, for the same velocities, divided by five, are the friction heads due to one pair of burrs for the respective velocities. These results were plotted in Fig. 6 and Line 35 drawn through the same; from this line Eq. 35 was determined as recorded under Table 22.

In the same manner the friction heads due to a pair of burrs in a 1 inch pipe were found and represented by Line 39 in Fig. 6 and by Eq. 39, recorded under Table 24.

From Eqs. 39 and 35 it appears that the injurious effect of failing to ream the ends of pipes is much more serious in the case of small pipes than in the case of larger pipes.

A comparison of Eq. 35 with Eq. 6 shows that the injurious effect of the burrs in a 3/4 inch pipe decreases with the velocity

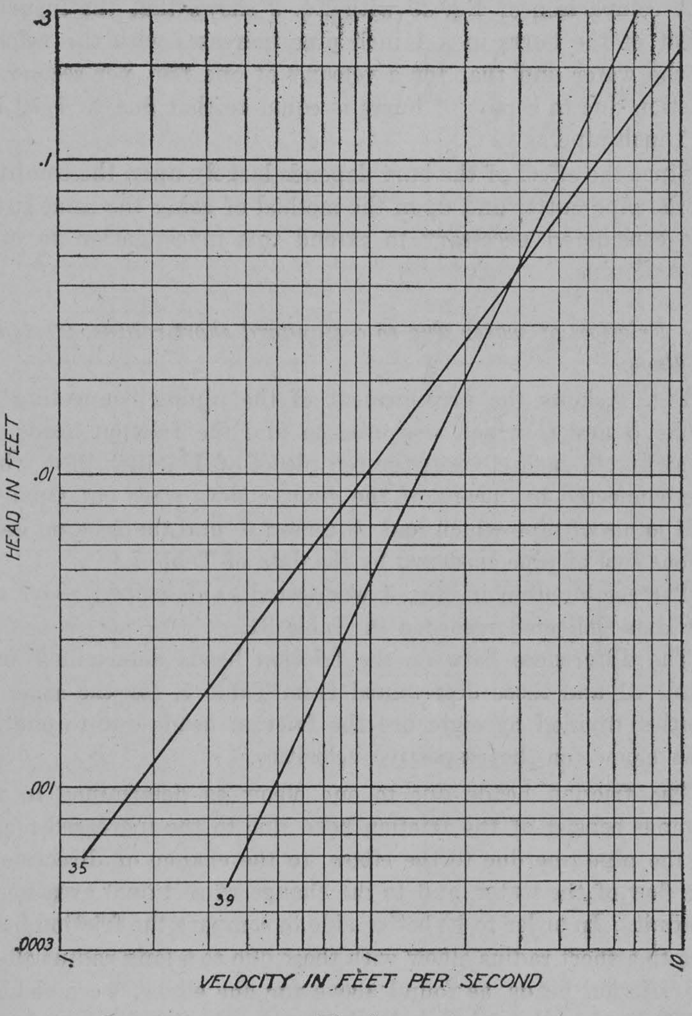

.3
.1
.01
.001
.0003
HEAD IN FEET
35
39
1
1
10
VELOCITY IN FEET PER SECOND

Fig. 6

of the water and that for a velocity of 1 foot per second the friction due to a pair of burrs is equal to that due to 1.2 feet of ¾ inch pipe.

A comparison of Eq. 39 with Eq. 9 shows that the injurious effect of the burrs in a 1 inch pipe increases with the velocity of the water and that for a velocity of one foot per second the friction due to a pair of burrs is equal to that due to 7/10 feet of 1 inch pipe.

Since the effect of the burr depends largely upon the condition of the pipe cutter and upon the method of using the same it was not considered necessary to extend this investigation to other sizes of pipe.

F. Friction of water due to a standard short-radius, 90 degree elbow.

Fig. 1 shows the arrangement of the piping connecting the tanks *B* and *C* which was used to find the friction heads due to eight 1¼ inch elbows; the ten pieces of 1¼ inch pipe which are connected by means of the eight elbows were cut from the two joints of pipe which had been used to find the friction heads in one foot of pipe as shown by the data of Table 7.

The combination in Fig. 1 was tested as described above and the data collected recorded in Table 31.

The differences between the friction heads determined from Table 31 and those determined from Table 7, for the same velocities, divided by eight are the friction heads due to one 1¼ inch elbow for the respective velocities.

The friction heads due to one elbow as determined in this manner consist of the friction head due to the increased length of the pipe line due to the elbow, to the change of direction of the flow of the water, and to the change of sectional area of the conduit. In order to be better able to compare the friction heads due to a short radius elbow with those due to a long radius elbow, the friction heads, as found above for one elbow, were reduced by deducting the friction heads due to the increase in length of the piping due to the elbow. For example, in the case of a 1¼ inch short radius elbow the distance from the end of one pipe to the point of intersection of the center lines of the pipes connected by the elbow, and from that point to the end of the other pipe was .208 feet; the friction heads due to a straight pipe of

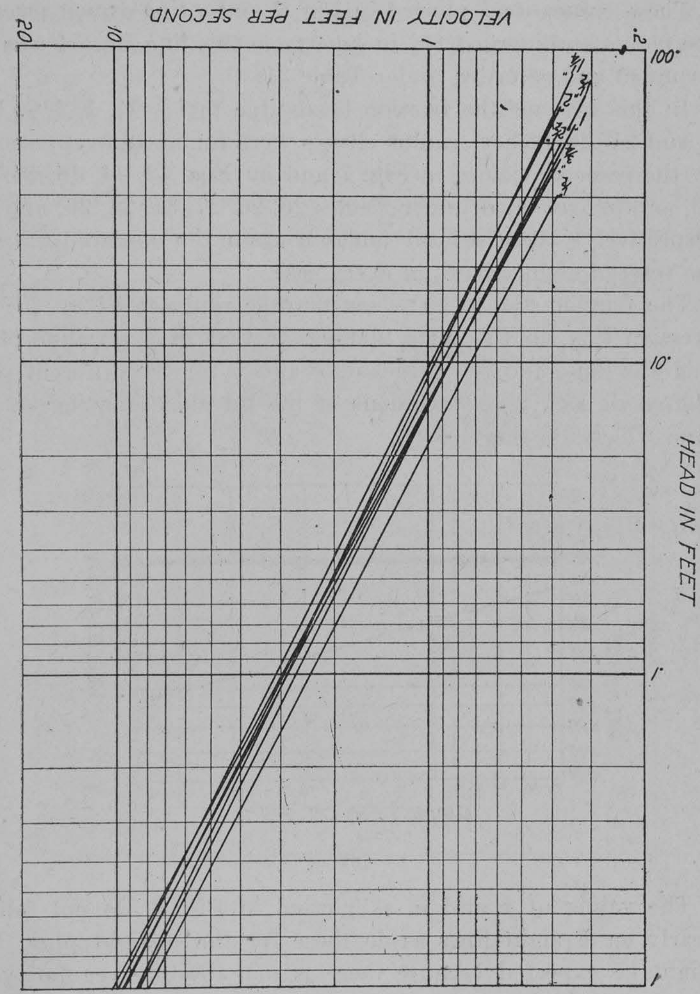


Fig. 7

that length, for the several velocities, were deducted from the friction heads as found above and the differences recorded as the friction heads due to one elbow.

These values were plotted in Fig. 7 and a line drawn through the points and marked 1¼ inches; from this line Eq. 54 was determined and recorded under Table 31.

In this manner the friction heads due to ½, ¾, 1, 1¼, 1½, 2, and 2½ inch short radius elbows were found and represented by the respective lines in Fig. 7 and by Eqs. 42, 44, 46, 54, 48, 50, and 52, recorded under Tables 25, 26, 27, 31, 28, 29, and 30, respectively; these several tables contain the observed data of the tests of eight elbows in every case.

The friction due to an elbow may be represented by the expression $k\,v^n$, in the same manner as that of a straight pipe; this was done and the values of k and n for the different sizes plotted in Fig. 8, as functions of the internal diameter of the pipe which fits the elbow.

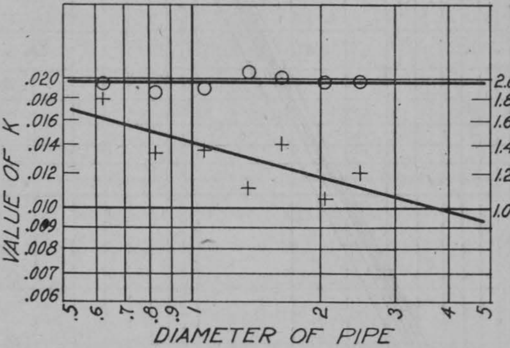


Fig. 8

The values of k and n, as plotted in Fig. 8, do not fall as nearly on straight lines as do those for the straight pipe; this might be expected because there is not absolute regularity in the change of the shape of the different elbows nor in the distances to which the several pipes are screwed into the elbows; there seemed, however, to be a gradual change in the values of k and n, so two lines were drawn to represent, as nearly as possible, the average values of those functions.

The equations of the two lines, as drawn in Fig. 8, are

$n = 1.96,$

$k = .0141\ d^{-0.26};$

consequently, the general equation for the friction heads of water in one standard, black, short radius, 90 degree elbow, as shown at *B*, Fig. 9, is

$$h = .0141 \frac{v^{1.96}}{d^{0.26}} \qquad \text{(Eq. 67).}$$

when the temperature of the water is about 70° F., and when the elbow sizes and the velocity of the water do not differ ma-

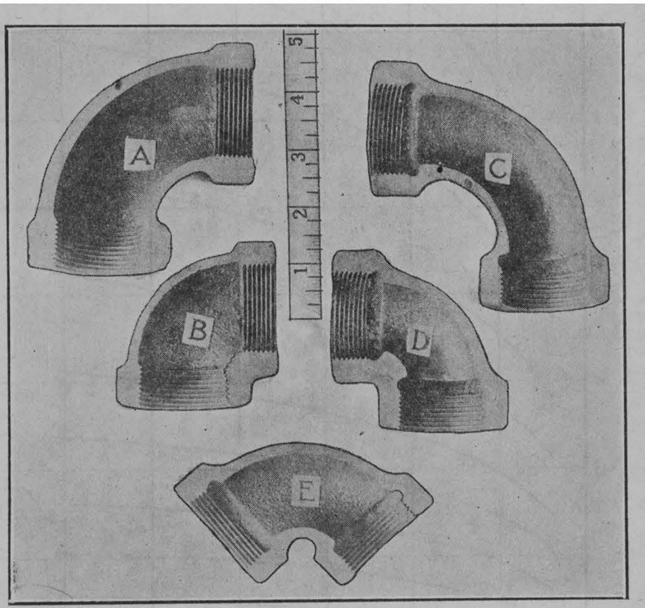


Fig. 9

terially from those used in these experiments.

In this formula

v=velocity of water in feet per second,

d=internal diameter, in inches, of the pipe which fits the elbow,

h=the friction head of water in one elbow, expressed in feet of water of the same density as that which flows through the elbow.

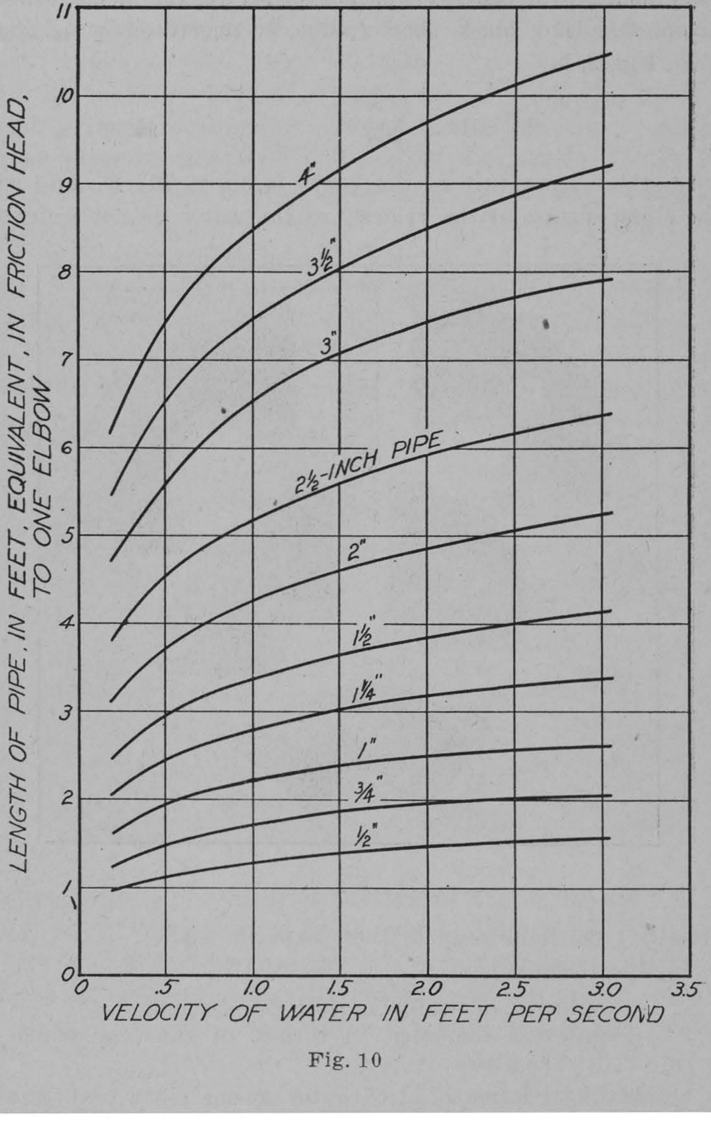

LENGTH OF PIPE, IN FEET, EQUIVALENT, IN FRICTION HEAD, TO ONE ELBOW
VELOCITY OF WATER IN FEET PER SECOND
0
1
2
3
4
5
6
7
8
9
10
11
.5
1.0
1.5
2.0
2.5
3.0
3.5
4"
3½"
3"
2½-INCH PIPE
2"
1½"
1¼"
1"
¾"
½"

Fig. 10

It is sometimes convenient to compare the friction heads due to one elbow with that due to a straight pipe of a certain length. This can be easily done by comparing Eqs. 66 and 67; in this manner Fig. 10 was prepared, to show the number of feet of straight pipe which, at the different velocities, have the same friction heads as one elbow.

From this diagram it is apparent that, for the sizes and velocities represented, the friction in one elbow is equal to the friction in a straight pipe of corresponding size if the length of the pipe is from 20 to 30 times its own diameter.

G. The difference in the friction of water in drainage and ordinary elbows, and in short and long radius elbows.

The difference between the friction of water in ordinary and in drainage elbows, and the difference between that in short radius and long radius elbows was determined by testing the five types of $1\frac{1}{4}$ inch elbows shown in Fig. 9.

In this figure

B is the ordinary short radius elbow,
A is the ordinary long radius elbow,
D is a short radius drainage elbow,
C is a long radius drainage elbow,
E is a long radius drainage elbow of a different type.

The tests were made, in every case, as described above for the short radius, 90 degree elbow, and included, in every case, eight elbows.

The results of these tests are shown

For elbow *A*, in Table 32, by Line 56 in Fig. 11, and by Eq. 56 under Table 32;
For elbow *B*, in Table 31, by Line 54 in Fig. 11, and by Eq. 54 under Table 31;
For elbow *C*, in Table 34, by Line 60 in Fig. 11, and by Eq. 60 under Table 34;
For elbow *D*, in Table 33, by Line 58 in Fig. 11, and by Eq. 58 under Table 33;
For elbow *E*, in Table 35, by Line 62 in Fig. 11, and by Eq. 62 under Table 35.

A comparison of these lines and equations shows that the friction of water in drainage elbows is greater than that in ordinary elbows; that the friction in short radius elbows is greater

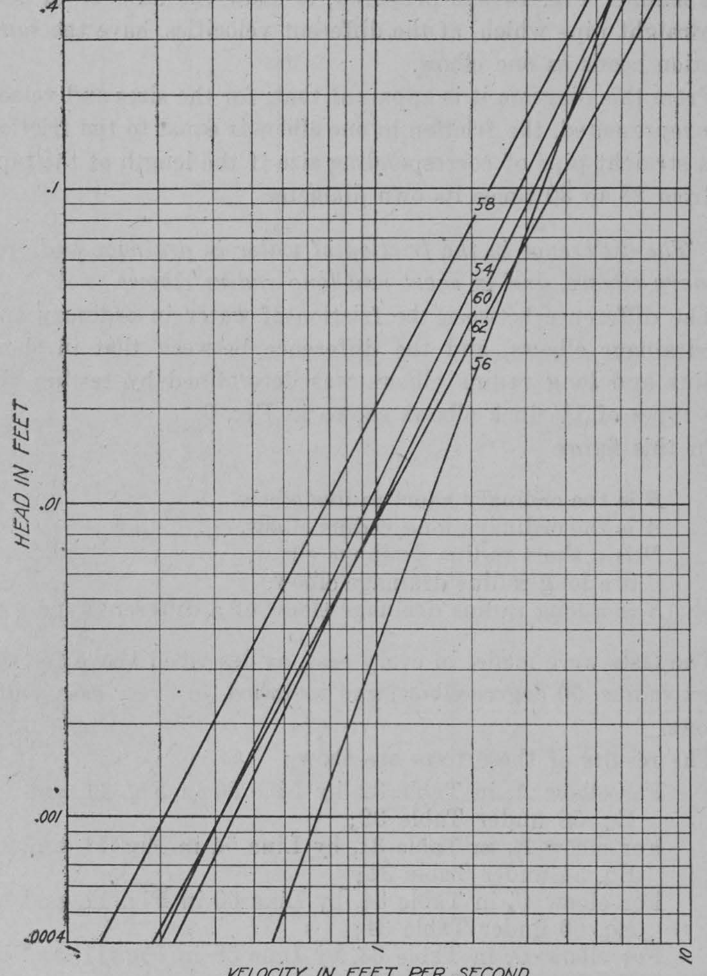

.4
.1
.01
.001
.0004
HEAD IN FEET
58
54
60
62
56
.1
1
10
VELOCITY IN FEET PER SECOND

Fig. 11

than in long radius elbows and that this difference varies considerably with the velocity of the water in the case of ordinary elbows and only slightly in the case of drainage elbows; that the friction in short radius ordinary elbows is about the same as that in long radius drainage elbows, in the case of the $1\frac{1}{4}$ inch elbows tested in these experiments.

H. The effect of temperature on the friction of the water in pipes and fittings.

By using water of different temperatures in the apparatus employed for the tests described above, the effect of the temperature of the water on the friction of water in pipes and fittings was studied.

The temperature of the water was regulated by allowing varying proportions of cold and hot water to flow into the tank *A*; temperature readings were taken continuously of the water in the upper portions of the tanks *B* and *C*, at the outlet of the tank *B*, and at the inlet of the tank *C*; the average values of these readings are shown in Fig. 12.

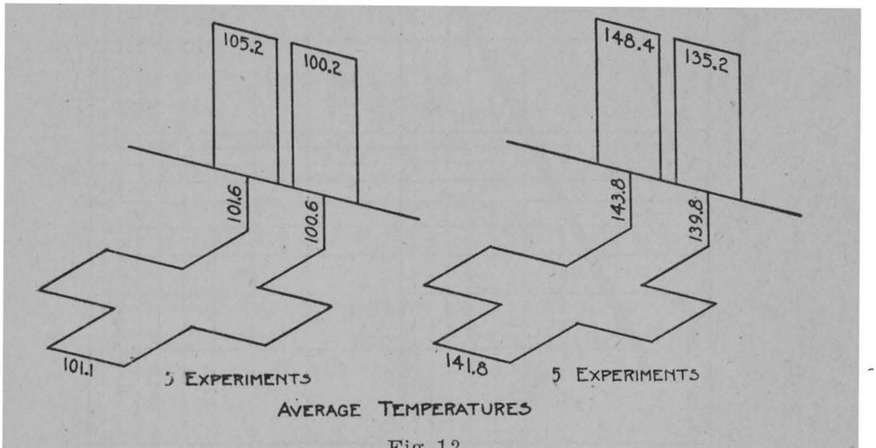
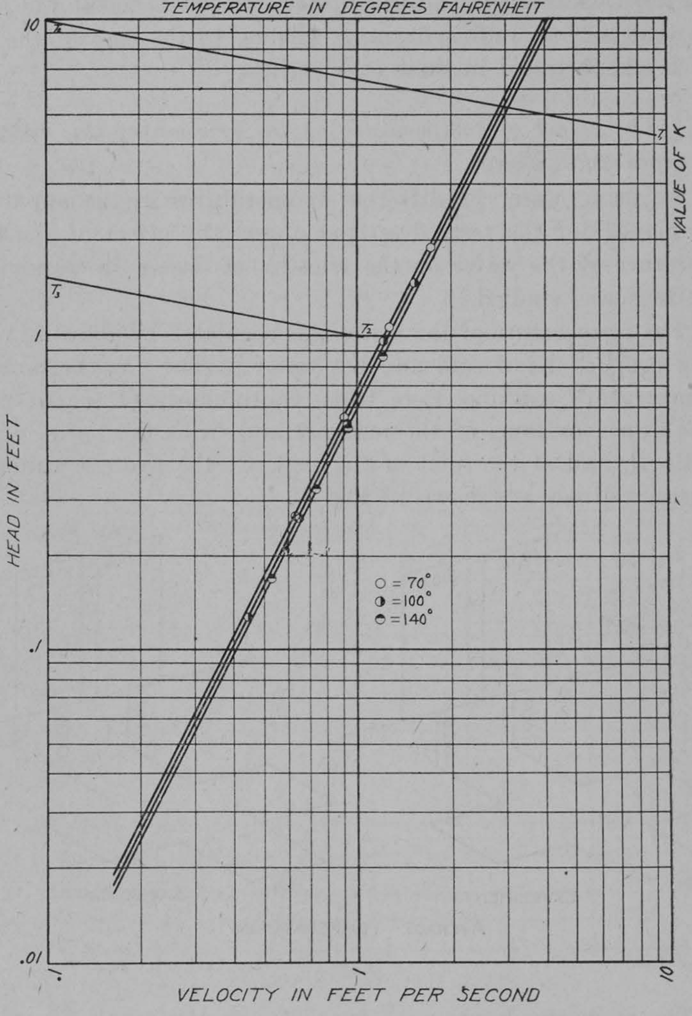


Fig. 12

The pressure heads were found by measuring the elevation of the water in the two tanks above that of the horizontal pipe connecting the tanks, and calculating the weight of each column of water at its respective, average temperature; the difference in weight, of these two columns of water, expressed in feet of



TEMPERATURE IN DEGREES FAHRENHEIT
HEAD IN FEET
VALUE OF K
VELOCITY IN FEET PER SECOND
10
1
.1
.01
○ = 70°
◑ = 100°
◓ = 140°

Fig. 13

water of the average temperature of that flowing through the pipe, was the corresponding pressure head.

Three sets of tests were made; in each test the temperature of the water was kept as nearly constant as possible, at 70 degrees, 100 degrees, and 140 degrees, respectively.

The results of these tests are recorded in Tables 36, 37, and 38, and plotted in Fig. 13.

The results of these tests are perhaps not quite as uniform as might be secured; and it is desirable to repeat them, making a larger number of tests, and covering a wider range of temperature.

From the results obtained it was not quite certain whether the three lines shown in Fig. 13 should be parallel; they were drawn parallel because that seemed to give a good average value in each case. The equations determined from these lines are shown under Tables 36, 37, 38, as Eqs. 63, 64, and 65.

These equations do not represent the friction in one foot of pipe or in one elbow, but in the entire combination of pipes and fittings shown in Fig. 1, except that ¾ inch pipe was used so as to increase the velocity in the pipe and reduce the drop in temperature in the pipe.

If it is correct to draw the lines, shown in Fig. 13, parallel, the effect of a change in the temperature of the water on the general equation, $h=kv^n$, of the friction of water in pipes or elbows is to change the value of k and not the value of n.

The three lines of Fig. 13, representing 70 degrees, 100 degrees, and 140 degrees, respectively, intersect the 1 foot velocity line at .670, .623, and .587.

The value of k in the general expression of the friction in a straight pipe (Eq. 66) is .00685 for a temperature of 70 degrees; for temperatures of 100 degrees and 140 degrees this would become .00637 and .00600 respectively, if changed in the ratios expressed by the numbers .670, .623, and .587.

By plotting the values .00685, .00600, and .00637 as functions of the temperature, expressed in Fahrenheit degrees, the line TT was found; its equation is $k=.01533t^{-.19}$, consequently, the general equation for the friction of water in new, clean, black standard pipe is

$$h=\frac{.01533}{t^{.19}}\frac{v^{1.77}}{d^{1.275}} \qquad \text{(Eq. 68)}$$

In this equation

h=friction head in one foot of pipe, expressed in feet of water of the same density as that which flows through the pipe,

v=velocity of the water in feet per second,

t=temperature of water in Fahrenheit degrees,

d=internal diameter of the pipe in inches.

General Remarks

The experimental investigation described above was begun in the fall of 1916: the actual execution of the experiments was in the hands of Miss Nellie Jefferson, B. S. in Architecture.

To a certain extent this investigation was a continuation and expansion of a study of the friction of water in standard galvanized iron pipe made by the writer in 1911-12.

The principal results of the earlier investigation were published in Domestic Engineering, November 12, 1912; to compare them with those of the experiments described in this bulletin the values of *k* and *n*, in the expression $h = k\,v^n$, for ¾, 1, 1¼, 1½, and 2 inch pipe, as published in Domestic Engineering, were shown in Fig. 4 and that figure reproduced below as Fig. 14.

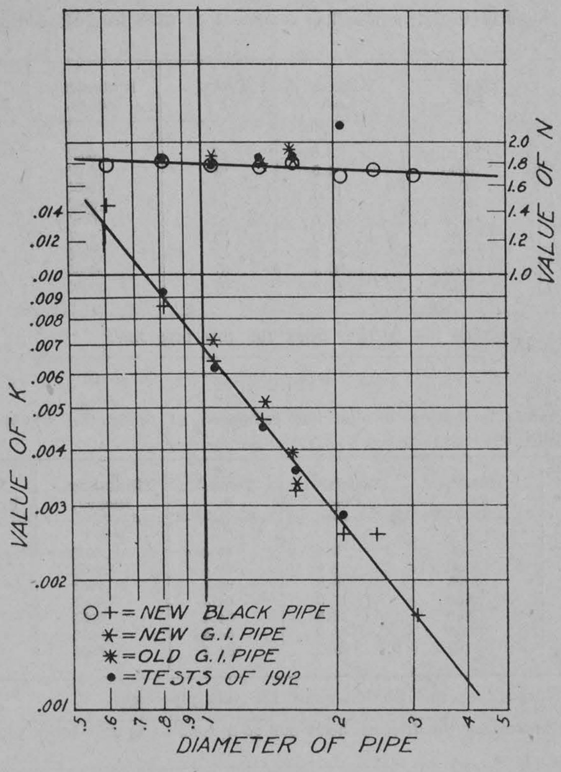

2.0
1.8
1.6
1.4
1.2
1.0
VALUE OF N
.014
.012
.010
.009
.008
.007
.006
.005
.004
.003
.002
.001
VALUE OF K
○+ = NEW BLACK PIPE
✳ = NEW G. I. PIPE
✳ = OLD G. I. PIPE
• = TESTS OF 1912
.5
.6
.7
.8
.9
1
2
3
4
5
DIAMETER OF PIPE

Fig. 14

TABLE 1.

Observed values in testing a pipe line composed of 40.88 feet of ½-inch black pipe and constants.

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
8-00	.0100	3.0	67	.6055	.0501
5-00	.0230	4.5	67	.6055	.1201
5-00	.0550	10.0	67	.6055	.2670
5-00	.0765	12.5	67	.6055	.3340
5-00	.1010	16.0	67	.6055	.4270
5-00	.1635	18.0	67	.6055	.4810
5-00	.3020	25.5	67	.6055	.6810
5-00	.4165	30.0	67	.6055	.8010
5-00	.7310	41.0	67	.6055	1.0950

Equation representing the friction head for this pipe line:
$h=.623v^{1.832}$ ---------- (1)

TABLE 2.

Observed values in testing a pipe line composed of 16.352 feet of ½-inch black pipe and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.0060	3.0	64.4	.6055	.1801
5-00	.0130	5.5	64.4	.6055	.1468
5-00	.0225	8.5	64.4	.6055	.2270
5-00	.0630	17.0	64.4	.6055	.4540
5-00	.3340	42.0	64.4	.6055	1.1220
5-00	.6275	58.0	64.4	.6055	1.5490
5-00	1.4100	89.0	64.4	.6055	2.3750

Equation representing the friction head for this pipe line:
$h=.271v^{1.90}$ ---------- (2)

Equation representing the friction head due to 1 foot of ½-inch black pipe. (From Eqs. 1 and 2):
$h=.014335v^{1.776}$ ---------- (3)

TABLE 3.

Observed values in testing a pipe line composed of 39.76 feet of ¾-inch black pipe and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.0060	4.5	66	.8175	.0661
5-00	.0143	8.5	66	.8175	.1248
5-00	.0713	27.0	66	.8175	.3968
5-00	.1580	40.5	66	.8175	.5950
5-00	.1585	39.5	66	.8175	.5810
5-00	.3145	58.5	66	.8175	.8580
5-00	.9150	105.0	66	.8175	1.5500
5-00	2.0200	163.25	66	.8175	2.4000

Equation representing the friction head for this pipe line:
$h=.417v^{1.803}$ ---------- (4)

TABLE 4.

Observed values in testing a pipe line composed of 15.904 feet of ¾-inch black pipe and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.0040	5.0	67	.8175	.0734
5-00	.0058	6.5	67	.8175	.0955
5-00	.0100	10.5	67	.8175	.1543
5-00	.0160	15.5	67	.8175	.2276
5-00	.0810	39.5	67	.8175	.5800
5-00	.1740	61.0	67	.8175	.8960
5-00	.7600	137.5	67	.8175	2.0200

Equation representing the friction head for this pipe line:

$h=.213v^{1.793}$ ---------- (5)

Equation representing the friction head due to 1 foot of ¾-inch black pipe. (From Eqs. 4 and 5):

$h=.00855v^{1.812}$ ---------- (6)

TABLE 5.

Observed values in testing a pipe line composed of 41.4 feet of 1-inch black pipe and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.0030	7.00	64	1.06	.0612
5-00	.0080	14.00	64	1.06	.1224
5-00	.0205	25.75	64	1.06	.2248
5-00	.0645	46.00	64	1.06	.4020
5-00	.1780	80.75	64	1.06	.7050
5-00	1.1040	222.00	64	1.06	1.9380

Equation representing the friction head for this pipe line:

$h=.337v^{1.805}$ ---------- (7)

TABLE 6.

Observed values in testing a pipe line composed of 8.28 feet of 1-inch black pipe and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.0017	8.0	64	1.06	.0699
5-01	.0031	12.0	64	1.00	.1043
5-00	.0095	27.0	64	1.06	.2360
5-00	.0170	39.0	64	1.06	.3406
5-00	.0265	49.0	64	1.06	.4280
5-00	.0750	88.0	64	1.06	.7680
5-00	.3465	200.5	64	1.06	1.7520
5-00	1.0590	360.0	64	1.06	3.1450

Equation representing the friction head for this pipe line:

$h=.126v^{1.85}$ ---------- (8)

Equation representing the friction head due to 1 foot of 1-inch black pipe. (From Eqs. 7 and 8):

$h=.006371v^{1.7767}$ ---------- (9)

TABLE 7.

Observed values in testing a pipe line composed of 41.07 feet of 1¼-inch black pipe and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.0060	19.5	65	1.361	.1030
5-00	.0037	13.5	65	1.361	.9714
5-00	.0100	29.0	75	1.361	.1531
5-00	.0165	43.0	65	1.361	.2270
5-00	.0450	70.5	65	1.361	.3725
5-00	.1135	118.5	65	1.361	.6260
5-00	.6135	300.5	65	1.361	1.5900
5-00	1.0960	410.5	65	1.361	2.1700

Equation representing the friction head for this pipe line:

$h = .2695v^{1.81}$ -- (10)

TABLE 8.

Observed values in testing a pipe line composed of 16 feet of 1¼-inch black pipe and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.0015	12.00	66	1.361	.0635
5-00	.0040	23.25	66	1.361	.1229
5-00	.0045	25.50	66	1.361	.1348
5-00	.0105	44.00	66	1.361	.2325
5-00	.0250	71.00	66	1.361	.3750
5-00	.0705	125.50	66	1.361	.6740
5-00	.2175	231.00	66	1.361	1.2210
5-00	.7450	447.00	66	1.361	2.3600

Equation representing the friction head for this pipe line:

$h = .1523v^{1.86}$ -- (11)

Equation representing the friction head due to 1 foot of 1¼-inch black pipe. (From Eqs. 10 and 11):

$h = .004675v^{1.756}$ -- (12)

TABLE 9.

Observed values in testing a pipe line composed of 42.59 feet of 1½-inch black pipe and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.0020	13.50	66	1.615	.0510
5-00	.0040	24.25	66	1.615	.0917
5-00	.0050	31.00	66	1.615	.1170
5-00	.0020	21.00	68	1.615	.0795
5-00	.0160	65.50	67	1.615	.2470
5-00	.0165	66.50	66	1.615	.2519
5-00	.0625	138.50	67	1.615	.5220
5-00	.1780	247.00	67	1.615	.9320
5-00	.4210	396.00	67	1.615	1.4920

Equation representing the friction head for this pipe line:

$h = .201v^{1.813}$ -- (13)

TABLE 10.

Observed values in testing a pipe line composed of 17.036 feet of 1½-inch black pipe and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.0030	29.0	67	1.615	.1090
5-00	.0033	31.0	67	1.615	.1166
5-00	.0075	54.5	67	1.615	.2050
5-00	.0365	140.0	67	1.615	.5260
5-00	.0890	229.0	67	1.615	.8620
5-00	.1415	294.0	67	1.615	1.1050
4-00	.3460	386.75	65	1.615	1.8300
4-00	.5390	483.00	65	1.615	2.2700

Equation representing the friction head for this pipe line:

$h=.1185v^{1.811}$ ---------- (14)

Equation representing the friction head due to 1 foot of 1½-inch black pipe. (From Eqs. 13 and 14):

$h=.003228v^{1.7998}$ ---------- (15)

TABLE 11.

Observed values in testing a pipe line composed of 41.84 feet of 2-inch black pipe and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.0095	75.00	71	2.044	.1756
5-00	.0265	138.00	71	2.044	.3235
5-00	.0475	195.00	71	2.044	.4570
5-00	.0795	256.00	71	2.044	.6000
5-00	.1460	358.00	71	2.044	.8390
5-00	.1800	401.00	71	2.044	9400
4-30	.3155	492.50	71	2.044	1.2850
3-30	.5050	493.00	71	2.044	1.6540

Equation representing the friction head for this pipe line:

$h=.201v^{1.825}$ ---------- (16)

TABLE 12.

Observed values in testing a pipe line composed of 16.15 feet of 2-inch black pipe and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.0025	47.0	72	2.044	.1101
5-00	.0075	88.0	72	2.044	.2060
5-00	.0070	88.5	72	2.044	.2075
5-00	.0133	124.5	72	2.044	.2915
5-00	.0278	181.5	72	2.044	.4260
5-00	.0525	257.0	72	2.044	.6025
5-00	.0755	312.5	72	2.044	.7330
5-00	.1060	374.0	72	2.044	.8760
5-00	.1965	520.75	72	2.044	1.2210
3-30	.3675	506.5	70	2.044	1.6980
2-50	.5945	528.0	70	2.044	2.1850

Equation representing the friction head for this pipe line:

$h=.136v^{1.89}$ ---------- (17)

Equation representing the friction head due to 1 foot of 2-inch black pipe. (From Eqs. 16 and 17):

$h=.00253v^{1.6787}$ ---------- (18)

TABLE 13.

Observed values in testing a pipe line composed of 36.06 feet of 2½-inch black pipe and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.003	49.0	69	2.48	.0765
5-00	.009	89.5	69	2.48	.1455
5-00	.024	165.5	69	2.48	.2638
5-00	.041	223.0	69	2.48	.3560
5-00	.058	269.5	69	2.48	.4295
5-00	.0995	359.5	69	2.48	.5730
5-00	.1450	441.0	69	2.48	.7030
4-00	.300	525.5	69	2.48	1.0480
3-00	.518	526.0	69	2.48	1.4000

Equation representing the friction head for this pipe line:

$h=.278v^{1.839}$ ---------- (19)

TABLE 14.

Observed values in testing a pipe line composed of 10 feet of 2½-inch black pipe and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.0035	63.0	70	2.48	.1004
5-00	.0085	104.5	70	2.48	.1667
5-00	.0170	161.5	70	2.48	.2575
5-00	.0360	242 5	70	2.48	.3870
5-00	.0495	286.5	70	2.48	.4570
5-00	.0765	364.0	70	2.48	.5800
5-00	.1365	495.5	70	2.48	.7900
3-30	.2690	496.5	70	2.48	1.1300
3-00	.3630	496.0	70	2.48	1.3190

Equation representing the friction head for this pipe line:

$h=.212v^{1.87}$ ---------- (20)

Equation representing the friction head due to 1 foot of 2½-inch black pipe. (From Eqs. 19 and 20):

$h=.00253v^{1.735}$ ---------- (21)

TABLE 15.

Observed values in testing a pipe line composed of 30.5 feet of 3-inch black pipe and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.0220	186.0	71	3.062	.1940
5-00	.0366	244.0	71	3.062	.2545
5-00	.0650	335.0	71	3.062	.3495
5-00	.0925	405.5	71	3.062	.4225
4-50	.1580	521.5	71	3.062	.5630
4-00	.2070	492.5	71	3.062	.6430
3-30	.2570	482.5	71	3.062	.7200
3-30	.2870	514.0	71	3.062	.7650
3-00	.3320	472.0	71	3.062	.8210
2-50	.4260	508.0	71	3.062	.9360
2-40	.4700	503.5	71	3.062	.9840

Equation representing the friction head for this pipe line:

$h=.487v^{1.96}$ ---------- (22)

TABLE 16.

Observed values in testing a pipe line composed of 9.43 feet of 3-inch black pipe and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.0215	192.0	72	3.062	.2005
5-00	.0390	267.5	72	3.062	.2790
5-00	.0545	321.0	72	3.062	.3350
5-00	.1005	444.0	72	3.062	.4630
4-10	.1765	495.0	72	3.062	.6200
3-30	.2520	497.0	72	3.062	.7420
3-00	.3140	476.0	72	3.062	.8290
2-50	.4060	516.0	72	3.062	.9520
2-40	.4540	512.0	72	3.062	1.0030

Equation representing the friction head for this pipe line:

$h=.452v^{1.98}$ ---------- (23)

Equation representing the friction head due to 1 foot of 3-inch black pipe. (From Eqs. 22 and 23):

$h=.00166v^{1.679}$ ---------- (24)

TABLE 17.

Observed values in testing a pipe line composed of 41.88 feet of 1-inch galvanized iron pipe and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.0160	20.5	66	1.06	.1790
5-00	.0296	30.0	66	1.06	.2620
5-00	.1090	59.5	66	1.06	.5200
5-00	.7325	164.5	66	1.06	1.4380

Equation representing the friction head for this pipe line:

$h=.3700V^{1.68}$ ---------- (25)

Equation representing the friction head due to 1 foot of 1-inch galvanized iron pipe. (From Eqs. 26, 7, and 9):

$h=.0071098V^{1.869}$ ---------- (26)

TABLE 18.

Observed values in testing a pipe line composed of 41.245 feet of 1¼-inch valvanized iron pipe and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.0449	70.5	66	1.385	.3600
5-00	.2084	164.5	65	1.385	.8400
5-00	.8670	356.0	65	1.385	1.8150

Equation representing the friction head for this pipe line:

$h=.2895V^{1.83}$ ---------- (27)

Equation representing the friction head due to 1 foot of 1¼-inch galvanized iron pipe. (From Eqs. 27, 10, and 12):

$h=.005139V^{1.789}$ ---------- (28)

TABLE 19.

Observed values in testing a pipe line composed of 39.73 feet of 1½-inch galvanized iron pipe and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.0460	118.5	69	1.626	.4400
5-00	.1220	205.5	69	1.626	.7610
5-00	.1315	214.0	69	1.626	.7950
5-00	.2550	309.0	69	1.626	1.1470
5-00	.2725	319.5	71	1.626	1.1850
5-00	.3625	374.0	71	1.626	1.3880
5-00	.5520	473.5	69	1.626	1.7500

Equation representing the friction head for this pipe line:

$h=.1975V^{1.81}$ .... (29)

Equation representing the friction head due to 1 foot of 1½-inch galvanized iron pipe. (From Eqs. 29, 13, and 15):

$h=.003373V^{1.8115}$ .... (30)

TABLE 20.

Observed values in testing a pipe line composed of 36.46 feet of 1½-inch galvanized iron pipe and constants. (Pipe used in greenhouse about seven years):

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.0145	62.5	69	1.6	.2398
5-00	.0280	89.5	69	1.6	.3432
5-00	.0800	156.5	69	1.6	.6001
5-00	.1695	234.5	69	1.6	.9000
5-00	.3245	331.5	69	1.6	1.2710
5-00	.6040	459.5	69	1.6	1.7620
4-30	.8670	500.0	69	1.6	2.1320
4-00	1.0060	480.0	69	1.6	2.3000
4-00	1.1920	521.0	69	1.6	2.5000

Equation representing the friction head for this pipe line:

$h=.207V^{1.89}$ .... (31)

Equation representing the friction head due to 1 foot of 1½-inch galvanized iron pipe. (From Eqs. 31, 13, and 15):

$h=.003935V^{1.927}$ .... (32)

TABLE 21.

Observed values in testing a pipe line composed of 39.76 feet of ¾ inch black pipe, 8 couplings, 14 unreamed ends, and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.0169	9.5	67	.8175	.1395
5-00	.2467	45.0	67	.8175	.6610
5-00	.6100	76.5	67	.8175	1.1240
5-00	1.3460	121.5	67	.8175	1.7860

Equation representing the friction head for this pipe line:

$h=.5002V^{1.728}$ .... (33)

TABLE 22.

Observed values in testing a pipe line composed of 39.76 feet of ¾-inch black pipe, 8 couplings, and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.0265	14.0	68	.8175	.2038
5-00	.1060	31.0	68	.8175	.4560
5-00	.7160	91.0	68	.8175	1.3380
5-00	1.1185	116.5	68	.8175	1.7110

Equation representing the friction head for this pipe line:

$h = .4285V^{1.78}$ .... (34)

Equation representing the friction due to one pair of unreamed ends in a ¾-inch pipe. (From Eqs. 33 and 34):

$h = .01024V^{1.375}$ .... (35)

Equation representing the friction due to one ¾-inch coupling. (From Eqs. 34 and 4):

$h = .001465V^{1.139}$ .... (36)

TABLE 23.

Observed values in testing a pipe line composed of 41.4 feet of 1-inch black pipe, 8 couplings, 14 unreamed ends, and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.0185	22.0	66	1.06	.1920
5-00	.0290	29.0	66	1.06	.2530
5-00	.0306	28.5	66	1.06	.2490
5-00	.0910	52.0	66	1.06	.4540
5-00	.6720	157.0	66	1.06	1.3720

Equation representing the friction head for this pipe line:

$h = .374V^{1.827}$ .... (37)

TABLE 24.

Observed values in testing a pipe line composed of 41.4 feet of 1-inch black pipe, 8 couplings, and constants, but no unreamed ends:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.0926	55.0	65	1.06	.4810
5-00	.1501	73.0	65	1.06	.6375
5-00	.8658	192.5	65	1.06	1.6810

Equation representing the friction head for this pipe line:

$h = .342V^{1.795}$ .... (38)

Equation representing the friction due to one pair of unreamed ends in a 1-inch pipe. (From Eqs. 37 and 38):

$h = .004575V^{2.128}$ .... (39)

Equation representing the friction due to one 1-inch coupling. (From Eqs. 38 and 7):

$h = .000625V^{1.1913}$ .... (40)

TABLE 25.

Observed values in testing a pipe line composed of 30 feet of ½-inch black pipe, 8 elbows, and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.2760	27.5	79	.62	.7025
5-00	.4000	32.0	70	.62	.8170
5-00	.5770	40.5	79	.62	1.0340
5-00	.7570	45.5	79	.62	1.1620
5-00	.9570	53.0	79	.62	1.3530
5-00	1.1050	56.0	79	.62	1.4300
5-00	1.5780	67.5	79	.62	1.7250
5-00	1.7300	68.0	79	.62	1.7350
5-00	1.2780	57.5	79	.62	1.4700
5-00	2.3800	83.0	79	.62	2.1200

Equation representing the friction head for this pipe line:

$h=.56V^{1.97}$ ---------- (41)

Equation representing the friction due to one ½-inch elbow. (From Eqs. 41 and 3 and 1):

$h=.0180V^{1.945}$ ---------- (42)

TABLE 26.

Observed values in testing a pipe line composed of 40.1 feet of ¾-inch black pipe, 8 elbows, and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.1980	41.5	79	.818	.6080
5-00	.2200	44.0	79	.818	.6450
5-00	.4280	62.5	79	.818	.9160
5-00	.6590	79.0	79	.818	1.1580
5-00	.8860	92.0	79	.818	1.3490
5-00	1.2400	111.2	79	.818	1.6300
5-00	1.3830	117.0	79	.818	1.7150

Equation representing the friction head for this pipe line:

$h=.5075V^{1.87}$ ---------- (43)

Equation representing the friction due to one ¾-inch elbow. (From Eqs. 43, 4, and 6):

$h=.01344V^{1.856}$ ---------- (44)

TABLE 27.

Observed values in testing a pipe line composed of 41.4 feet of 1-inch black pipe, 8 elbows, and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.1587	64.5	64	1.06	.5635
5-00	.5390	126.0	64	1.06	1.1000
5-00	1.2420	199.0	64	1.06	1.7400

Equation representing the friction head for this pipe line:

$h=.454V^{1.83}$ ---------- (45)

Equation representing the friction due to one 1-inch elbow. (From Eqs. 45 and 7):

$h=.01358V^{1.896}$ ---------- (46)

TABLE 28.

Observed values in testing a pipe line composed of 42.59 feet of 1½-inch black pipe, 8 elbows, and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.0815	125.5	74	1.615	.4725
5-00	.2100	212.5	74	1.615	.8000
5-00	.3560	283.0	74	1.615	1.0660
5-00	.4890	337.0	74	1.615	1.2680
5-00	.9000	464.0	74	1.615	1.7450
4-20	1.3390	495.5	74	1.615	2.1520

Equation representing the friction head for this pipe line:

$h = .319V^{1.884}$ ---------- (47)

Equation representing the friction due to one 1½-inch elbow. (From Eqs. 47 and 13):

$h = .01405V^{2.0076}$ ---------- (48)

TABLE 29.

Observed values in testing a pipe line composed of 41.68 feet of 2-inch black pipe, 8 elbows, and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.1250	267.0	68	2.042	.6020
5-00	.2005	345.5	68	2.042	.7780
5-00	.4460	534.5	68	2.042	1.2020
3-40	.7720	525.5	68	2.042	1.6150

Equation representing the friction head for this pipe line:

$h = .3175V^{1.85}$ ---------- (49)

Equation representing the friction due to one 2-inch elbow. (From Eqs. 49, 16, and 18):

$h = .010574V^{1.963}$ ---------- (50)

TABLE 30.

Observed values in testing a pipe line composed of 36.03 feet of 2½-inch black pipe, 8 elbows, and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.1120	326.5	79	2.48	.5215
5-00	.1380	371.0	79	2.48	.5920
5-00	.1950	442.5	79	2.48	.7060
5-00	.2330	485.5	79	2.48	.7750
5-00	.2590	512.0	79	2.48	.8175
5-00	.3120	573.0	79	2.48	.8980
4-00	.3790	501.5	79	2.48	1.0000
3-35	.4650	503.5	79	2.48	1.1200

Equation representing the friction head for this pipe line:

$h = .38V^{1.875}$ ---------- (51)

Equation representing the friction due to one 2½-inch elbow. (From Eqs. 51 and 19):

$h = .01212V^{1.979}$ ---------- (52)

TABLE 31.

Observed values in testing a pipe line composed of 41.48 feet of 1¼-inch black pipe, 8 short radius ordinary elbows, and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.0105	23.5	71	1.35	.1263
5-00	.0255	41.0	71	1.35	.2205
5-00	.0420	56.0	71	1.35	.3010
5-00	.0560	66.5	71	1.35	.3580
5-00	.1435	113.0	71	1.35	.6090
5-05	.2680	160.0	71	1.35	.8470
5-00	.5590	236.0	71	1.35	1.2700
5-00	.9620	314.0	71	1.35	1.6910
5-00	1.7300	424.5	71	1.35	2.2810
5-00	2.0050	457.5	71	1.35	2.4650

Equation representing the friction head for this pipe line:

$h = .368V^{1.885}$ ________ (53)

Equation representing the friction due to one 1¼-inch short radius ordinary elbow. (From Eqs. 53, 10, and 12):

$h = .0111V^{2.0819}$ ________ (54)

TABLE 32.

Observed values in testing a pipe line composed of 41.48 feet of 1¼-inch black pipe, 8 long radius ordinary elbows, and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.2370	160.0	71	1.35	.8620
5-00	.4230	217.5	71	1.35	1.1700
5-00	.8610	297.0	71	1.35	1.5970
5-00	.9030	324.0	71	1.35	1.7430
5-00	1.6445	441.0	71	1.35	2.3750
5-00	2.0570	494.5	71	1.35	2.6600

Equation representing the friction head for this pipe line:

$h = .312V^{1.922}$ ________ (55)

Equation representing the friction due to one 1¼-inch long radius ordinary elbow. (From Eqs. 55, 10, and 12):

$h = .003322V^{2.784}$ ________ (56)

TABLE 33.

Observed values in testing a pipe line composed of 41.48 feet of 1¼-inch black pipe, 8 short radius drainage elbows, and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.0370	50.0	64	1.35	.2640
5-00	.0615	64.5	64	1.35	.3410
5-00	.1660	111.5	64	1.35	.5900
5-00	.6490	232.5	64	1.35	1.2300
5-00	1.2150	325.5	64	1.35	1.7200

Equation representing the friction head for this pipe line:

$h = .4415V^{1.862}$ ________ (57)

Equation representing the friction due to one 1¼-inch short radius drainage elbow. (From Eqs. 57, 10, and 12):

$h = .02009V^{1.9522}$ ________ (58)

TABLE 34.

Observed values in testing a pipe line composed of 41.48 feet of 1¼-inch black pipe, 8 long radius drainage elbows, and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.0360	52.0	63	1.35	.2750
5-00	.1780	129.5	63	1.35	.6850
5-00	.5720	243.5	63	1.35	1.2880
5-00	1.2170	362.5	63	1.35	1.9150

Equation representing the friction head for this pipe line:

$h = .36V^{1.865}$ ---------- (59)

Equation representing the friction due to one 1¼-inch long radius drainage elbow. (From Eqs. 59, 10, and 12):

$h = .008981V^{2.0745}$ ---------- (60)

TABLE 35.

Observed values in testing a pipe line composed of 41.48 feet of 1¼-inch black pipe, 8 long radius drainage elbows, and constants:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.0535	66.5	64	1.35	.3510
5-00	.1760	130.0	64	1.35	.6870
5-00	.6970	275.0	64	1.36	1.4550
5-00	1.5790	424.5	64	1.35	2.2400

Equation representing the friction head for this pipe line:

$h = .3515V^{1.82}$ ---------- (61)

Equation representing the friction due to one 1¼-inch long radius drainage elbow. (From Eqs. 61, 10, and 12):

$h = .008649V^{1.869}$ ---------- (62)

TABLE 36.

Observed values in testing a pipe line composed of 39.76 feet of ¾-inch pipe, 8 elbows, and constants at different temperatures:

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.2700	43.0	70	.8175	.6320
5-00	.5470	62.0	70	.8175	.9110
5-00	1.0570	87.0	70	.8175	1.2790
5-00	1.0565	86.5	70	.8175	1.2550
5-00	1.9050	118.0	70	.8175	1.7330

Equation representing the friction head for this pipe line with water at 70 degrees:

$h = .672V^{1.96}$ ---------- (63)

TABLE 37.

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.1256	30.0	102	.8175	.4420
5-00	.2640	44.0	101	.8175	.6470
5-00	.5270	62.5	101	.8175	.9210
5-00	.9580	86.0	100	.8175	1.2670
5-00	1.4640	104.5	106	.8175	1.5400

Equation representing the friction head for this pipe line with water at about 100 degrees:

$h = .624V^{1.96}$ ---------- (64)

TABLE 38.

Time Min.-Sec.	Head Ft.	Weight Lbs.	Temp. F.	Diameter Inches.	Velocity Ft. per Sec.
5-00	.5090	63.0	143	.8175	.9340
5-00	.8710	82.5	141	.8175	1.2240
5-00	.1665	35.5	142	.8175	.5260
5-00	.2070	40.0	141	.8175	.5930
5-00	.3261	49.5	141	.8175	.7320

Equation representing the friction head for this pipe line with water at about 140 degrees:

$h = .583V^{1.96}$ ---------- (65)